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**CALIBRATION OF ACCELEROMETERS
USING THE RATE TABLE AT
THE DCIEM IMPACT STUDIES FACILITY**

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ABSTRACT

A method for calibrating linear accelerometers using the rate table at the DCIEM Impact Studies Facility (ISF) and the ISF computer is described. The method uses the Datalab transient recorders at the ISF to perform up to 4096 measurements of the accelerometer output voltage and the rate table angular velocity, as the angular velocity is varied. The data from these measurements are used to calculate the slope and intercept of the line of best fit relating the measured output voltage to the centripetal acceleration calculated from the angular velocity. A computer program controls the process of data transfer, data selection and data reduction. The accelerometer output voltage can be plotted as a function of acceleration, if required.

1. REASONS FOR THE CALIBRATION PROCEDURE

Periodic verification of the sensitivity of accelerometers is a requirement in any impact studies laboratory, since many test procedures rely on acceleration measurements to determine the acceptability of crash protection and restraint systems. The DCIEM Impact Studies Facility (ISF) Rate Table was constructed for this purpose. It incorporates a vertical-axis rotor, bearing a 60-cm diameter aluminium wheel, which can be rotated by a motor at up to 800 revolutions per minute. At this speed, it creates a centripetal acceleration of over 200 times gravity at its rim. An internal tachometer on the wheel axis generates a DC-voltage proportional to the speed of the wheel, the output being 1.00 volt per 100 revolutions per minute or 95 millivolts per radian per second (± 1 percent). At the centre of the wheel is a two-amplifier circuit to which two accelerometers can be directly connected while mounted on the wheel. The outputs of the amplifiers are relayed, via slip rings, to connectors on the Rate Table control panel.

Calibrations of accelerometers can be performed by setting the Rate Table speed control to different speeds and simultaneously measuring the voltage from the tachometer output and the voltage from the accelerometer amplifier using an accurate digital voltmeter. This process is tedious and must be followed by manual calculation of the centripetal[†] acceleration from the tachometer voltage and comparison of this with the accelerometer voltage.

A simpler, more efficient method of doing this is to record the tachometer and amplifier output signals using the Datalab Model 4001 (Data Laboratories Ltd., Mitcham, England) transient recorders of the ISF and to transfer these data to the ISF Model pdp-11/34A computer (Digital Equipment Corp. (DEC), Marlboro, U. S. A.) These are part of the data acquisition system of the ISF, and have been described by Bowden *et al.*²

The Rate Table is initially set to a high speed and allowed to attain that speed. During the recording of the signals, the Rate Table speed is allowed to decrease from this maximum to zero by setting the speed control to zero and allowing friction to stop the rotation, a process which takes about 85 seconds. The recorded signal thus contains samples taken at all speeds between the maximum and zero. This allows the calibration of accelerometers over a large effective range.

Programs written for the ISF computer allow the direct calculation of a best estimate of the accelerometer sensitivity and internal offset by computer. The computation takes about 10 minutes, and the resulting calibration can be based on up to 4000 separate measurements, a great improvement over the manual method.

2. THE PROCEDURE IN DETAIL

2.1. Connections

The accelerometers must be mounted on the wheel, using the appropriate brackets, and connected to the inputs of the amplifiers via their own cables. *Two identical accelerometers, mounted on identical brackets, should be installed so that the wheel is balanced.* The cables should be wound around the amplifier case and fastened in position with a strong adhesive tape.

[†] The word "centripetal" is used here, rather than the more commonly-used adjective "centrifugal", in order to indicate that the actual acceleration to which the accelerometer is exposed is directed towards the centre of its rotation. The "centrifugal force" is not a real force, but one which must be postulated in order to explain the behaviour of massive objects, as described in a rotating reference frame, using normal Newtonian dynamics. See, for example, Marion's *Classical Dynamics of Particles and Systems*, (second edition),¹ page 345.

At this time, the radius of rotation of the accelerometers should be accurately measured, since this datum is required for the calibration. This is most easily done by holding a flat piece of metal (an unused mounting bracket) against each mounting bracket so that part of the metal projects above the amplifier housing in the centre of the rotor. A steel tape measure can then be used to measure the distance between the mounting planes of the accelerometers (preferably in centimetres). If the mounts are identical, (as they should be), this distance is twice the radius of rotation.

The outputs of the Rate Table tachometer and amplifier must be connected to the Datalab recorders via co-axial cable. This can be done directly, or through the umbilical signal cable of the ISF HyGe sled, if necessary.

2.2. Warm-up

Turn on the amplifiers of the Rate Table and the Datalab transient recorders at least thirty minutes before performing the first calibration. A warm-up of at least this length is required for reproducible results. After this period, the Rate Table amplifier gain is within 0.5% of its specified value of 200. This can be verified using a signal generator and an accurate voltmeter.

If the Rate Table has not been used within the past month it should be run before the calibration, to ensure good contact at the slip rings. Turn on the Rate Table motor power at least 5 minutes before the first calibration, and, after ensuring that the rotor is clear of loose parts and tools, turn the main control to "RUN" and advance the dial to a speed setting of about 30.

2.3. Preparation of the Datalab Recorders

1. Choose two Datalab recorder channels connected to the upper Datalab controller. The first to be read should be connected to the Rate Table tachometer output, and the second, to one of the accelerometer amplifier outputs. The input coupling of the recorders should be set to DC mode. The data capture and analysis program assumes that there is only one accelerometer to be calibrated in any one reading.
2. Set the sample rate of the upper Datalab controller to 20 milliseconds per sample. This will make the total recording period 81.92 seconds.
3. Set the internal delay of the upper controller to 2800 samples, (rather than the usual setting of 3800 samples). As a result of this, a period of 25.92 seconds before the trigger will be recorded. This is sufficient to allow a person to turn off the Rate Table, walk to the Datalab recorders and manually trigger the recorder. The recording ends a few seconds before the rotor comes to a stop.
4. On the Datalab recorder which records the tachometer output, set the full-scale to 20 volts, and the Offset dial to 3.00. This will provide the correct range to record the tachometer output as the rotor speed varies from nearly full speed to zero during the calibration.
5. Determine, by experiment, the correct Full Scale and Offset settings of the Datalab recorder which is recording the accelerometer output. The Datalab recorder should be able to record all of
 - (i) zero volts,
 - (ii) the lowest output voltage from the amplifier, and
 - (iii) the highest output voltage from the amplifier.

This can be done in either of two ways:

- a. Measure the output voltage from the amplifier with a voltmeter at the Rate Table, as the speed control is varied through the full range. Set the Datalab recorders so that all of these voltages are spanned by the recording range.
- b. Connect the amplifier output to the appropriate Datalab recorder channel, press the "MAN ARM" button on the controller, and run the Rate Table to the limits of the

selected speed range. While the Rate Table is running, observe the OVER-RANGE indicator lights on the Datalab recorder channel. (This can be done from the Experimental Laboratory Area near the Rate Table by looking through the Control Room window.) Ensure that, at the limits of the speed range, neither OVER-RANGE light is on.

The correct Full Scale and Offset setting should be set on the Datalab recorder channels, and noted for inclusion in the Parameter Table prepared just before the data capture.

2.4. Measurement

A stopwatch or a watch that indicates seconds should be on hand. The steps are as follows:

1. Arm the Datalab recorders.
2. Ensure that the Rate Table is clear of loose tools and fasteners.
3. Turn the Rate Table "Power" switch to "ON".
4. Momentarily move the Rate Table control switch to "RUN".
5. Set the Speed Control of the Rate Table to the desired speed. A setting of 74 will produce about 170 G at the rim of the rotor.
6. Allow the Rate Table to run for about 20 seconds, so that the speed is stabilized.
7. Turn the Speed Control dial quickly to zero. *Note the time.* (Do not set the Rate Table control switch to "BRAKE".)
8. Walk directly to the Datalab recorders.
9. Between 21 and 24 seconds after Step 7, press the "MAN TRIGGER" button on the Datalab controller.
10. Fifty-six seconds after Step 9, the Datalab recorders will halt recording, and, if the "READ" lights of the recorder channels are on, the recorded signals will be displayed on the monitor oscilloscope.
11. If the recorded signals are acceptable, start the transfer to the computer and the analysis by executing the computer program described below under "Analysis".
12. An additional recording of both the tachometer and amplifier output signals is required to determine the system offsets, as part of the procedure for analysis. The computer program will prompt the operator to do this recording at the appropriate time.

The program for analyzing the data will require some manual entries at the beginning, but, after a point, will run by itself. At this time, return to the Rate Table and either prepare for another calibration or turn the Rate Table off.

2.5. Analysis of the data

2.5.1. Theory

The raw data recorded by the Datalab recorders are scaled to produce true values of

- a. the angular velocity of the Rate Table rotor in radians per second, and
- b. the output of the accelerometer in millivolts.

This scaling is performed in two steps. The first step is to multiply the numbers read from the Datalab transient recorders by the appropriate factors which produce these real values, apart from an additive constant, due to possible errors in setting the "OFFSET" dials. This step is performed by the computer program "ISPB", which uses data from the Parameter Table in the file produced by the data transfer program. The Parameter Table in the file "ACCCAL.DAT" on the "PROGRAMS #7" RK05 disk at the ISF contains the correct scaling factors for this process

(apart from the Full-scale and Offset values for the Accelerometer output channel). Its contents are reproduced in Table 1. (For an explanation of the labels of Table 1, see Bowden *et al.*²)

The second step is to refine these values by subtracting the scaled numbers which correspond to the raw numbers which the Datalab recorders assign to

- a. zero volts output from the tachometer, and
- b. zero volts from the amplifier.

This corrects the effect of errors in the "OFFSET" settings of the Datalab recorders.

After scaling the data, the computer calculates the linear acceleration at the position of the accelerometer from the angular velocity using the formula:

$$G = \frac{r \omega^2}{g_0}$$

where

- G is the acceleration in units of g_0 .
- r is the radius of rotation at the seismic centre of the accelerometer.
- ω is the angular velocity of the rotor in radians per second, and
- g_0 is the acceleration of gravity, $980.4 \text{ cm-sec}^{-2}$.

The remaining step is to calculate the slope and intercept of the line of best fit for the accelerometer output in millivolts as a function of the acceleration in G . This step is performed by the program "CORREL" which prints the range of values of acceleration and accelerometer output voltage used, the slope and intercept of the line of best fit, and the coefficient of correlation, R , of the regression. Values of R greater than 0.999 can be expected in calibration tests.

Because of the scaling of the input variables, the slope of the line of best fit is the actual calibration sensitivity of the accelerometer in millivolts per G . The intercept is the offset of the accelerometer in millivolts.

2.5.2. Procedure

The analysis procedure is greatly simplified by the use of an Indirect Control File named "ACCCAL.COM", which is on the "PROGRAMS #7" RK05 disk pack at the ISF. The file is a list of prompts, directives, and commands which are interpreted by the Indirect Control File Processor, "IND", which is part of the RT-11 operating system supplied by the Digital Equipment Corporation. The Indirect Control File Processor is described in Chapter 4. of the *System User's Guide* which is part of the RT-11 Version 5 documentation. The complete text of the file "ACCCAL.COM" is given in the Appendix.

To start the analysis, load the "PROGRAMS #7" disk into the RK05f disk drive RK2, and another disk into the RK05f drive RK3 on the ISF computer. The RK3 disk should have at least 400 contiguous blocks of free space, and the RK1 disk should also have at least 400 contiguous blocks of free space.

The following commands must be typed in response to the RT-11 period (.) prompt:

._SET KMON IND

and either of the two commands listed below.

._@ACCCAL

._@ACCCAL "ACCID" "nn.nn"

In the second of the above commands: "ACCID" stands for an unique identifier for the file in which the data are to be recorded, and "nn.nn" is the numerical value of the radius of rotation in cm. ACCID must be six characters, and can be made up of the accelerometer serial number and

the test number, e. g. AH5901 for the first test of accelerometer AH59.

If the command "@ACCCAL" is used, the computer will ask you to enter the file identifier and the radius separately, as follows:

Enter the accelerometer ID: "ACCID"

Confirm: Accelerometer ID is "ACCID"

Enter the radius of rotation in cm: "nn.nn"

Confirm: Radius of rotation is "nn.nn" cm.

The computer will then ask if the Parameter Table is to be changed. This is usually necessary if an accelerometer is being tested for the first time, since the appropriate Full Scale and Offset settings for the accelerometer will not have previously been entered into the table.

Do you want to change the Parameter Table [Y/N]

The response is "Y" if the table is to be changed, "N" otherwise. If the response is "Y", the program "PARAM" is run with the editor option, and this allows the user to enter the appropriate changes in the Parameter Table. See the documentation for the program "PARAM" for instructions. The only changes required will be in the Full-Scale and Offset values for Channel 2.

At this point, the Datalab recorders should have recorded the data from the test and should be prepared for the transfer of data to the computer. The program assumes that there are two channels of data to be read, the first containing the tachometer output, and the second containing the accelerometer amplifier output. The two channels should be on the first Datalab controller. The computer prompts with:

Are you ready for the data transfer?

Pressing the "RETURN" key in response to this prompt will start the data transfer, and cause the message: "The data are being transferred." to appear. There may be problems with the data transfer which will cause diagnostic messages from the program "DATA" to appear. See the documentation for this program for explanations.

After the data transfer is completed, the following message will appear.

To calibrate the tachometer output one should now record the signal on the Datalab when the rate table is still.

You should also press the "GND" button on the second transient recorder module: this will allow the computer to determine the absolute accelerometer offset.

You can speed up the recording process by pressing in the "Sample Rate A" button.

Remember to release the buttons when you are finished.

Are you ready for the zero data transfer? [Y/N, D:Y]

The second recording is made by manually arming and triggering the recorder, after pressing the buttons described in the prompt. Pressing the "RETURN" key will initiate the second data transfer. These data, which establish the true "zero-volt" values for the Datalab recorders, are recorded in a file on the RK3 disk called "ZERO.DAT". Again, there may be problems with the data transfer which cause messages from "DATA" to appear.

At this time, the computer displays:

The computer will now display the accelerometer output using the GLITCH program.

Choose the beginning and end point for the slope region over which you want the correlation to be taken. Note these points; you will be asked for them later.

Use the GLITCH commands to remove the obvious "glitches" from the accelerometer record; this will improve your result.

Are you ready for the display? [Y/N:D:Y]

When the "RETURN" key is pressed, the program "GLITCH" is used to display the record of the accelerometer output (Channel 2). The display usually resembles the second graph in Figure 1. At the left, the line is level for a short segment; the starting point should be to the right of this point. Move the cursor to this point and press the 'S' key. You should note the *address* value displayed in the lower part of the screen. If there is a flat region at the right, the ending point should be to the left of this. Move the cursor to this point and press the 'F' key. Again the *address* displayed on the screen should be noted.

There may be "glitches" in the sloping part of the record caused by temporary drop-outs of the signal. These are displayed as short lines extending vertically below the line of the recorded accelerometer output. *Note that the initial display does not show all of the points; if there are any glitches shown, the whole record should be examined at a higher magnification to detect all of the glitches.* The method for changing the magnification and repairing glitches is described in the documentation for the "GLITCH" program. The "GLITCH" program allows one to write the changes into the file and inspect the tachometer output record, if necessary.

After the "GLITCH" program is stopped (by entering '0' in response to the "Channel?" prompt), the computer then prompts for the entry of the points which define the range over which the regression will be calculated.

Enter the beginning point [1:4096:D:1]

Enter the end point [mmm:4096:D:4096]

The default values for the responses to the first prompt is 1, and for responses to the second prompt is 4096. The "mmm" in the second prompt will be replaced by the number entered in response to the first prompt. If the second number entered is smaller than the first, the computer will prompt again for the second number.

At this point, the computer has acquired all of the information required for the processing of the data. The only remaining prompt is the question:

Do you want plots of the results?

A 'Y' response will cause the computer to generate four graphs on two pages, in addition to the printed output. An additional reminder appears on the terminal screen to prepare the Calcomp 1012 drum plotter (Calcomp, Inc, Anaheim, CA, U. S. A.). The plotter should be indexed on a new sheet of paper, and should have a pen mounted in holder number 1.

Examples of the graphs produced are given in Figures 1 to 4. An example of the printed output is given in Figure 5.

As explained above, the sensitivity of the accelerometer in millivolts G is given in the printed output as the "Slope of best-fit line:". The "Y - intercept of line:" is the internal offset of the accelerometer, i. e., that voltage which is produced when the acceleration is zero.

Other useful data produced by the correlation program include:

- a. The minimum and maximum of the range of accelerations used. These are the two numbers in the line:

1st variable runs between n.nnnnnE+nn and m.mmmmmE+nn

- b. The minimum and maximum of the range of output voltages (from the accelerometer rather than the amplifier) produced. These two numbers come from the following line.
- c. The minimum (greatest negative) and maximum (greatest positive) deviations from the line of best fit are given in the last two lines of the printed output. These numbers usually will correspond to "glitches" in the accelerometer output record. The actual deviation from the straight line of best fit can be plotted by indexing the Calcomp plotter on a fresh sheet of paper and entering the commands:

```
↓RUN COMPLT
*RK1:ACCCAL/V:6/V:5
INDEX THE PLOTTER before the next entry
Enter the limits of the time range to be plotted (ms): mmmm.nnn.
*** PLOTTING BEGINS *****
***** Plotting Finished *****
↑C
```

The values represented by mmmm. and nnn. are calculated by multiplying the beginning and ending sample numbers chosen for the correlation by 20.

3. RESULTS OF A TEST OF THE PROCEDURE

In preparation for a series of impact tests using the nine-accelerometer mount, ten accelerometers were calibrated using the method described above. Six of these were Endevco Model 2264-2000 accelerometers (Endevco, San Juan Capistrano, CA, U. S. A.) and four were Endevco Model 2264A-2000 accelerometers. The accelerometer serial numbers are given in Table 2.

Accelerometer AH59 was tested seven times, partly because of changes in the amplifier due to warm-up, and partly as part of the development of the analysis procedure. The last two of these analyses are given in Table 2. Table 3 gives values for the sensitivity obtained in tests 3 to 7, which show the effect of amplifier warm-up and an indication of the linearity of the accelerometer.

Table 3 shows that the amplifier gain decreases slightly (about 7%) on warm-up, and approaches the correct value in three hours. Table 2 shows that the agreement between the manufacturer's calibration and the results of this method is better than 1%, except in one case. For this reason, it is reasonable to state that the manufacturer's calibration for accelerometer CF16A is in error, or that the characteristics of the accelerometer have changed. (This accelerometer had not been used since delivery by Endevco, so there is no explanation for the discrepancy.)

The gain of the amplifiers in the Rate Table, and the accuracy of the tachometer were not checked during these tests. The results indicate that, after warm-up, the amplifier gain is accurate to better than 1%. Further improvements in accuracy would require repeated calibration checks and accurate temperature control.

4. CONCLUSIONS

The procedure described here is as accurate as possible, given the possibility of inherent errors in the tachometer and amplifiers of the Rate Table. It is simple and quick enough to be performed routinely. Regular calibration checks of the accelerometers will allow more confidence in results obtained at the DCIEM Impact Studies Facility.

5. REFERENCES

1. MARION, J. B. *Classical Dynamics of Particles and Systems, Second Edition*. Academic Press, Inc., New York, New York, U. S. A., 1970.
2. BOWDEN, T. J., J. K. REICHERT and J. P. LANDOLT. The Data Acquisition System at the DCIEM Impact Studies Facility. *Passenger Car Meeting*. Society of Automotive Engineers, Inc., Warrendale, PA, U. S. A., June 8-12, 1981. (SAE Paper No. 810812).

APPENDIX

A Listing of the Indirect Control File: ACCCAL.COM

```

.;Indirect control file for calibration of accelerometers on rate table.
    .ENABLE QUIET
    .DISABLE PREFIX
    .DISABLE OCTAL
SET TT: QUIET
ASS DK PRG
ASS RK3 DAT
; "[H"[J
    .OPEN #0 SY:TMP.COM
    .ENABLE DATA #0
R PARAME
PRG:ACCCAL=PRG:ACCCAL/E
^C
    .DISABLE DATA
    .CLOSE #0 SY:TMP.COM
;
    .SETN TEST <STRLEN>
    .IF TEST < 2 .ASKS [1:6] P1 Enter the accelerometer ID:
;         Confirm: Accelerometer ID is 'P1'
    .IF TEST < 3 .ASKS [1:6] P2 Enter the radius of rotation in cm:
;         Confirm: Radius of rotation is 'P2' cm.
;
    .IF P3 = "REPROCESS" .GOTO REDO
    .ASK [<FALSE>] LP Do you want to change the Parameter Table
    .IFT LP $QSY:TMP
DEL/NOQUERY SY:TMP.COM
    .ASK [<TRUE>] L1 "[5:10H"[2JAre you ready for the data transfer
;         The data are being transferred.
DATA1A PRG:ACCCAL DAT:'P1'/A:2
;
; "[5:10H"[2JTo calibrate the tachometer output you should
;         now record the signal on the Datalab when the rate table
;         is still.
;
;         You should also press the "GND" button on the second
;         transient recorder module; this will allow the
;         computer to determine the absolute accelerometer offset.
;
;         You can speed up the recording process by pressing in the
;         "Sample Rate A" button.
;
;         Remember to release the buttons when you are finished.
;
    .ASK [<TRUE>] L1         Are you ready for the zero data transfer
;         The data are being transferred.
DATA1A PRG:ACCCAL DAT:ZERO/A:2
;

```

```

.REDO:
: "[5:10H" [[2J The computer will now display the accelerometer output
: using the GLITCH program.
:
: Choose the beginning and end point for the slope region
: over which you want the correlation to be taken.
: Note these points; you will be asked for them later.
:
: Use the GLITCH commands to remove the obvious "glitches"
: from the accelerometer record; this will improve your
: result.
:
: .ASK [<TRUE>] L1 Are you ready for the display
GLITCH DAT:'P1'/C:2/O
: "[5:1H" [[2J
: .ASKN [1:4096:1] NSS Enter the beginning point
:
: .ASKN ['NSS':4096:4096] NSF Enter the end point
: .OPEN #0 SY:TMP.COM
: .ENABLE DATA #0
RUN PRG:ISPB
RK1:ACCCAL/V:4=DAT:'P1'/C:2/Z:ABS
ACCELEROMETER CALIBRATION
RK1:ACCZER/V:0.,NL:=DAT:ZERO/C:2/Z:ABS
ACCELEROMETER CALIBRATION ZERO
^C
RUN PRG:SUBTRA
RK1:ACCCAL/V:3,NL:=RK1:ACCCAL/V:1,RK1:ACCZER/V:1
ANG VEL RAD/S
RK1:ACCCAL/V:4,NL:=RK1:ACCCAL/V:2,RK1:ACCZER/V:2
ACCEL. OUT (MV)
^C
RUN PRG:ROTACC
RK1:ACCCAL/V:5=RK1:ACCCAL/V:3
ACC (G)
^P2^
^C
RUN PRG:CORREL
RK1:ACCCAL/V:6=RK1:ACCCAL/V:5:4/S:'NSS'./F:'NSF'.
DEVIATION (MV)
^C
PAGE
: .DISABLE DATA
: .CLOSE #0 SY:TMP.COM
: .ASK [<TRUE>] LP Do you want plots of the results
: .IFF LP .GOTO PROC
:
: "[1:7m Make sure the plotter is ready." [[0m
:
: .OPENA #0 SY:TMP.COM
: .ENABLE DATA #0
RUN PRG:PAGEFL
RK1:ACCCAL/V:3:4:5/P:1
BASIC DATA

```

```
^C
RUN PRG:COMPLT
RK1:ACCCAL/V:4:5/N
'NSS','NSF'
^C
.DISABLE DATA
.CLOSE #0 SY:TMP.COM
.PROC:
;          "[5;7mProcessing data."[[0m
$QSY:TMP
DEL/NOQUERY SY:TMP
; "[5;1H" [[2J
.STOP
```

Note: The sequence '^[' stands for the ESCAPE character (octal 033).

Table 1

A Parameter Table for Accelerometer Calibrations

CONTROLLER PARAMETERS:							
CONTROLLER #	SAMPLE RATE		PRETRIG		CHANNELS		
1	20000.00		1296.		2		
2	100.00		296.		0		

LABEL	FS	OS	CF	AG	AO	TC	FC
ANG VEL RAD/S	20.000	3.000	1.000	1.000	0.000	9.549E+01	0
ACCEL.OUT(MV)	10.000	9.000	1.000	200.0	0.000	1.000E+00	0

Table 2.
Calibrations of Ten Accelerometers

Accelerometer	Test #	Minimum G	Maximum G	Correlation Coeff. 'R'	Offset (mV)	Sensitivity (mV/G)	Manufacturer's Calibration (mV/G)
Endevco Model 2264-2000 accelerometers							
AH59	6	74	186	0.99803	8.12	0.2196	0.221
	7	81	187	0.99838	8.01	0.2204	
AF87	1	46	179	0.99910	-9.72	0.2162	0.216
	2	52	177	0.99944	-9.75	0.2168	
AC07	1	48	168	0.99976	-18.70	0.2036	0.204
	2	55	173	0.99970	-18.63	0.2039	
AN12	1	56	179	0.99967	2.16	0.2298	0.229
	2	58	179	0.99968	2.15	0.2300	
AN55	2	53	169	0.99965	-28.22	0.2160	0.215
	3	47	182	0.99970	-28.12	0.2164	
AH46†	1	58	77	0.98897	32.19	0.2437	0.248
	3	7	29	0.99620	31.78	0.2507	
Endevco Model 2264A-2000 accelerometers							
CF14A	1	45	163	0.99978	-15.46	0.2150	0.2154
	2	41	156	0.99978	-15.47	0.2150	
CF16A	1	37	152	0.99978	-3.09	0.2592	0.2161
	2	45	150	0.99976	-3.07	0.2600	
CF20A	1	44	153	0.99973	-53.80	0.2141	0.214
	2	44	163	0.99975	-53.74	0.2139	
CE96A	1	43	162	0.99981	-26.20	0.1962	0.1960
	2	46	164	0.99980	-26.18	0.1961	

† The large offset of this accelerometer prevented a calibration at higher accelerations.

Table 3.

Successive Calibrations of Accelerometer AH59

Manufacturer's stated value: 0.221 mV/G

Test #	Time†	Top G	Bottom G	Calibration (mv/G)
3	8:04	140	5	0.236
4	8:37	100	52	0.222
5	8:54	200	80	0.2229
5‡	8:54	108	21	0.2223
6	10:37	186	74	0.2196
7	10:46	187	81	0.2204

† The amplifiers were turned on at 8:00 o'clock.

‡ The analysis of test 5 was repeated using different ranges of acceleration in order to demonstrate the linearity of the accelerometer.

DCIEM IMPACT STUDIES FACILITY
PROJECT TITLE: ACCELEROMETER CALIBRATION
TEST RUN: AH5905
DATE: 13-FEB-85; TIME: 08:54:58.

BASIC DATA

PAGE 1

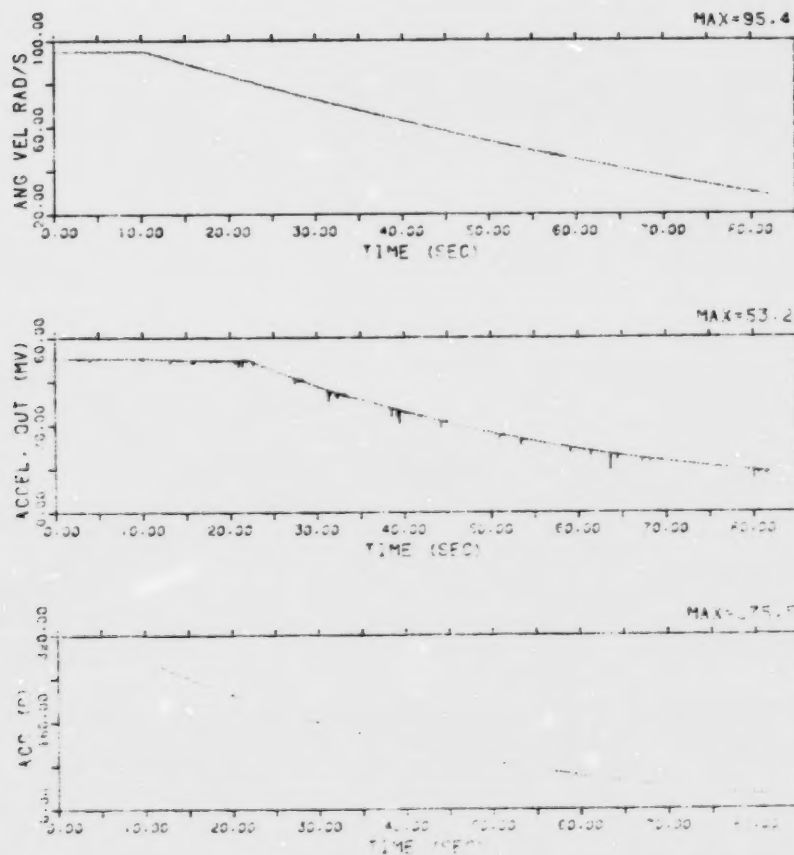


Figure 1:

Plots of rotor angular velocity, accelerometer output voltage in millivolts, and centripetal acceleration at the rotor rim for the fifth test of accelerometer AH59. Glitches can be seen in the accelerometer output record.

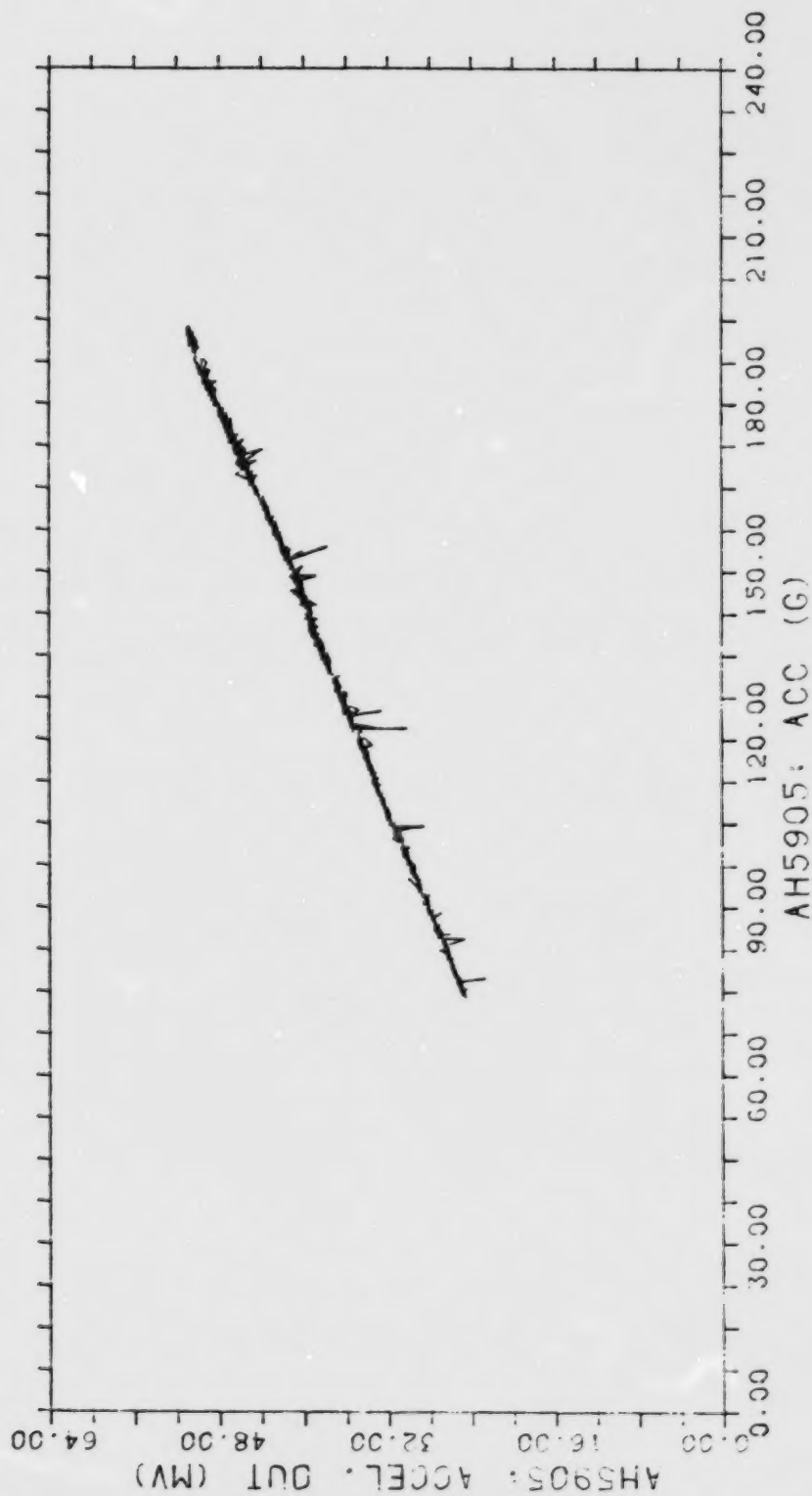


Figure 2:
Plot of the accelerometer output against centripetal acceleration in the fifth test of accelerometer AH59. The vertical deviations are the result of individual glitches in the accelerometer output; the occasional horizontal deviations are glitches in the tachometer output. Because individual points are linked by lines, this graph appears to overstate the significance of the glitches.

DCIEM IMPACT STUDIES FACILITY
PROJECT TITLE: ACCELEROMETER CALIBRATION
TEST RUN: AN5503
DATE: 13-FEB-85; TIME: 15:33:46.

BASIC DATA

PAGE 1

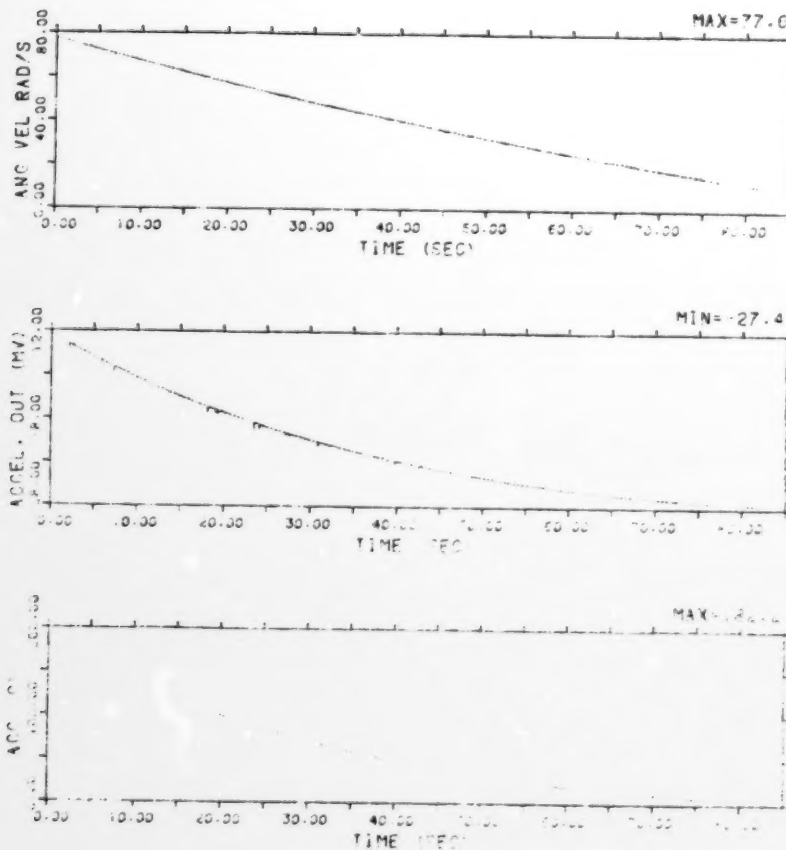


Figure 3:

Plots of rotor angular velocity, accelerometer output voltage in millivolts, and centripetal acceleration at the rotor rim for the third test of accelerometer AN55. Because of the improved performance of the slip rings when the measurement was performed, only a few glitches can be seen in the accelerometer output record.

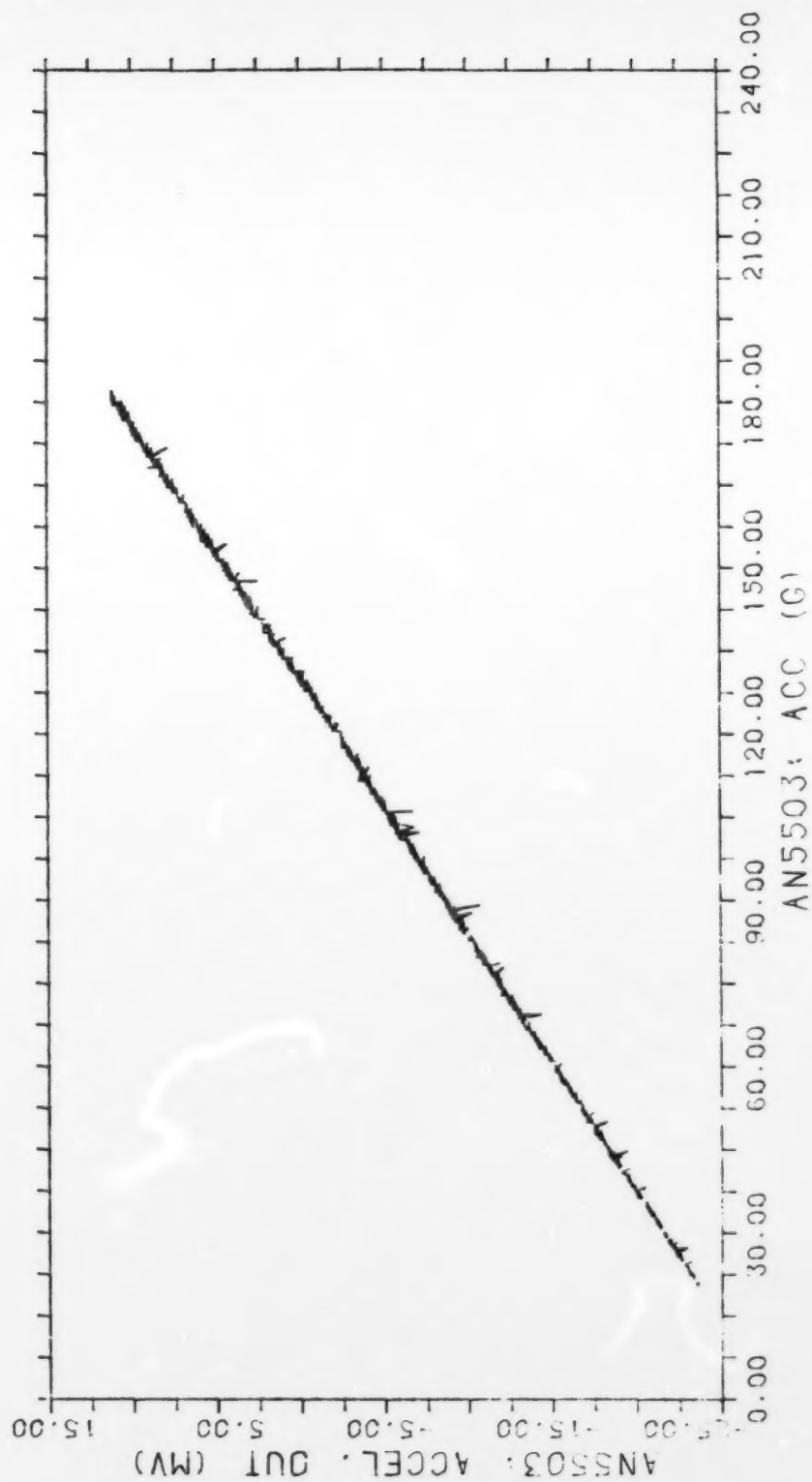


Figure 4:
Plot of the accelerometer output against centripetal acceleration in the third test of
accelerometer AN55.

DCIEM IMPACT STUDIES FACILITY
Data Processing Log

ACCELEROMETER CALIBRATION

Input data file: DAT:AN5503.DAT; Archive Date: 13-FEB-85; Time: 15:33:46.
Output Engineering Units file: RK1:ACCCAL.ENG
Processed at 15:47:25 on 13-FEB-85.

**** Parameter Table ****

CH #	LABEL	FS	OS	CF	AG	AD	TC	FC
1	ANG VEL RAD/S	20.000	3.000	1.000	1.000	0.000	0.955E+02	0
2	ACCEL. OUT (MV)	20.000	5.000	1.000	200.000	0.000	0.100E+01	0

CONTROLLER PARAMETERS:

CONTROLLER #	SAMPLE RATE	PRETRIG	CHANNELS
1	20000.00	1296.	2
2	100.00	296.	0

Output file has room for 6 variables.
Zero determination: ABS; Scaling: IMF.

Program: ROTACC.

Input Variable 1 from File: RK1:ACCCAL.ENG, Variable 3, Records 7 & 8.
Input Variable No. 1 Label: AN5503: ANG VEL RAD/S
Output written to File: RK1:ACCCAL.ENG, Variable 5, Records 11 & 12.
Output Variable Label: AN5503: ACC (G)

Radius of rotation is 29.67 cm.

Program: CORREL.

Input Variable 1 from File: RK1:ACCCAL.ENG, Variable 5, Records 11 & 12.
Input Variable No. 1 Label: AN5503: ACC (G)
Input Variable 2 from File: RK1:ACCCAL.ENG, Variable 4, Records 9 & 10.
Input Variable No. 2 Label: AN5503: ACCEL. OUT (MV)
Output written to File: RK1:ACCCAL.ENG, Variable 6, Records 13 & 14.
Output Variable Label: AN5503: DEVIATION (MV)

Regression of second variable on first.

Kanse starts at sample: 1; time : 2.00000E+02 sec.

Kanse ends at sample: 2937; time : 5.87400E+01 sec.

1st var. runs between 4.67608E+01 and 1.82204E+02

2nd var. runs between -1.82796E+01 and 1.11437E+01

Slope of best-fit line: 2.16362E-01

Y - Intercept of line: -2.81222E+01

Coefficient of Regression: 0.99970

Maximum deviation is 7.52062E-01 at sample number 152
Minimum deviation is -1.90362E+00 at sample number 1178

Figure 5:

Reproduction of the printed output of the analysis of the third test of accelerometer AN55.



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